

**Mechanical part of medium or small size
deriving from the forge or the press.**

The invention relates to mechanical parts of medium or small size made of medium carbon micro-alloyed steel, such as wheel hubs, connecting rods or swivels for an automobile, or other similar mechanical parts obtained through hot or cold plastic deformation of a long siderurgical semiproduct and for which there are sought, above all, properties of resistance to fatigue and of tenacity. By medium or small size, there is understood here parts the diameter of which does not exceed approximately 80 mm.

In order to produce such parts, it is known to make use of steels specially alloyed to obtain a metallographic structure of a bainitic or essentially bainitic type. By "essentially," there usually must be understood 80% and more by volume of the bainitic structure at the place on the part where this structure is sought.

Their manufacture in fact requires being able to withstand significant modifications in form without breaking or cracking, while in the end affording a good resistance to fragile breaking (tenacity) and fatigue in view of the cycles of repetitive stresses to which the parts are subjected in use, as well as to impacts (high resilience). Furthermore, these steels must afford good machinability characteristics, in order to permit a precise final dimensioning by machining of the part ready for use required in a number of applications.

The manufacturing process usually can comprise an operation of cold (press or forge) or hot (forge) plastic deformation, the choice of the hot or cold method often being made according to the final size of the parts. In all cases, this operation will be performed on pieces of steel cut up into bars deriving from long, continuously cast hot-rolled siderurgical semiproducts. When the plastic deformation is performed "hot," the pieces of steel are reheated beforehand to a temperature of approximately 1000 to 1200° C, then hot-formed in the forge. The parts obtained then are cooled and treated thermally by hardening and tempering. When the plastic deformation is performed "cold," the pieces are cold-formed in the press, possibly after having undergone a globularization annealing. The parts obtained then are treated thermally by hardening and tempering.

It is recalled that in service, these parts ordinarily are subjected to variable, even cyclic, mechanical stressing, which generates a significant fatigue effect. Steel fatigue is expressed by the occurrence of microfissures that propagate until breaking, even if the stress is lower than the tensile strength or the limit of elasticity of the metal that constitutes the part. Nowadays it is estimated that fatigue is responsible for nearly 90% of the breaking of mechanical parts in service. Likewise, the impacts that a mechanical part may undergo in service bring about the occurrence of microfissures that can cause the part to break prematurely if particular attention is not given to the resilience properties of the metal that constitutes it.

Now, the bainitic structure of the steel ordinarily appears in the form of parallel laths that consequently present few obstacles to the propagation of microfissures. This structure, although sought for its properties of mechanical resistance and ductility, does not necessarily afford a satisfactory tenacity or resistance to fatigue.

It is known, for example through document EP 0 787 812, to improve the fatigue resistance of forged parts by virtue of the presence of residual austenite within the bainite, obtained by means of an appropriate controlled cooling combined with the choice of a grade of steel the composition of which was specially enriched with silicon.

The purposes of the invention is to contribute another solution to the improvement of the fatigue resistance and tenacity of forged or pressed mechanical parts that preserves their high mechanical characteristics, for example of resistance, ductility and resilience.

To this end, the invention has as its purpose a mechanical part made of steel deriving from the hot forge or the cold press, of medium or small size, resulting from the plastic deformation of a long siderurgical semiproduct, characterized in that the steel of which it is composed has a composition which, besides iron and the inevitable residual impurities resulting from the processing of steel, corresponds at least to the following analysis, given in weight percentages:

0.2	≤	C	≤	0.5
0.5	≤	Mn	≤	2.0
0.05	≤	V	≤	0.5
0.6	≤	Si	≤	1.5
0.05	≤	Cr	≤	1.0
0.01	≤	Mo	≤	0.5
0.02	≤	S	≤	0.10

and possibly up to 50 ppm boron

and in that the said part is obtained from a long semiproduct deriving from continuous casting and hot-rolled in the austenitic area, then formed by plastic deformation and treated thermally to obtain a metallographic structure containing essentially acicular ferrite, at least in the zones of mechanical stressing in tenacity and fatigue.

By "essentially" there is understood here at least 50% and preferably 60%, or even advantageously 80% and more of acicular ferrite by volume.

The invention further has as its purpose a steel for the manufacture of a mechanical part by plastic deformation characterized in that, besides the inevitable residual impurities resulting from the processing of steel, its chemical composition includes at least, expressed in weight content:

0.2	≤	C	≤	0.5
0.5	≤	Mn	≤	2.0
0.05	≤	V	≤	0.5

0.6	≤	Si	≤	1.5
0.05	≤	Cr	≤	1.0
0.01	≤	Mo	≤	0.5
0.02	≤	S	≤	0.10

and possibly up to 50 ppm of B

and in that the metallographic microstructure that it will have, once the said part is implemented, is composed essentially of acicular ferrite at least in the zones of the part subjected to mechanical stressing in tenacity and fatigue.

With regard to both the mechanical part and the grade of steel defined hereinabove, in order to facilitate the obtaining of acicular ferrite, the steel furthermore includes preferably 5 to 30 ppm of Ca, and/or 0.01 to 0.02% Ti, with possibly up to 0.2% Al.

The invention further has as its purpose a process for manufacture of such a mechanical part made of steel characterized in that, with the goal of obtaining acicular ferrite at least locally on the said piece, it comprises the following stages:

- there is supplied a continuous-casting billet made of steel of a composition in accordance with the analysis given hereinabove, that is hot-rolled at a temperature in excess of 1000° C into a bar or wire before being cooled to room temperature after rolling;
- the wire being subjected to a controlled cooling prior to its formation into a ring for obtaining a metallographic structure composed essentially of acicular ferrite, which wire then is cut into pieces and cold-pressed into a finished part ready for use;
- the bar itself being cooled naturally in the rolling heat prior to its cutting into pieces which then are hot-forged into a rough shape of a part which is cooled by controlled cooling for obtaining a structure essentially composed of acicular ferrite at least in the stressed zones of the part, which rough shape then is machined, as need be, to the desired dimensions to make it into a finished part ready for use.

In a variation, the controlled cooling is a natural cooling to room temperature. In practice, in fact, it happens that the forged parts are stored immediately in bulk in buckets, on top of each other. The parts located on the top of the pile are going to cool more rapidly than those located underneath. A controlled cooling of each piece, therefore, is not sought at this stage, since they usually then are going to be treated thermally anyway.

On the other hand, in the process according to the invention, the parts certainly may cool naturally (that is, without blowing of air), but this cooling nonetheless must be controlled in order to ensure the formation of acicular ferrite. This control of the cooling may be accomplished, for example, by depositing the parts one by one, apart from each other, directly after the forge operation, on a conveyor belt that transports them to the receiving area of the works with a view to their storage prior to shipment.

According to a preferred variation of the invention, however, the controlled cooling is a forced cooling, for example with blown air, ensuring a surface cooling speed of approximately 0.5 to 15° C/s.

It is recalled that vocabulary practices in the siderurgical trade provide that rolled products with diameters ranging up to approximately 30 mm in diameter (which frequently are packaged in the form of rings) are referred to as "wire," and those rolled products starting from 18 mm in diameter and which are delivered straight after cutting lengthwise at the rolls outlet are referred to as "bars."

Finally, the invention has as its purpose a long, medium carbon siderurgical semiproduct, intended to be transformed by forge or cold press into a mechanical part with high characteristics, of small size or medium size, characterized in that the steel that constitutes it corresponds to the following analysis, given in weight percentages:

0.2	≤	C	≤	0.5
0.5	≤	Mn	≤	2.0
0.05	≤	V	≤	0.5
0.6	≤	Si	≤	1.5
0.05	≤	Cr	≤	1.0
0.01	≤	Mo	≤	0.5
0.02	≤	S	≤	0.10

and possibly up to 50 ppm of boron

and in that the metallographic microstructure that it will have after transformation will be composed essentially of acicular ferrite at least in the zones of the part subjected to mechanical stressing in tenacity and fatigue.

As undoubtedly will have been understood, the invention in fact consists in proposing the manufacture of a tough, resilient mechanical part endowed with a microstructure essentially composed of acicular ferrite at least in the zones of the part mechanically stressed in fatigue, from a medium carbon steel combined, in the analysis brackets given in these elements, with manganese (itself also gammagenic) for resistance to breaking, and micro-alloyed with vanadium supported by sulfur in order to promote the development of acicular ferrite and combined, firstly, with molybdenum in order to improve resilience and to harden the ferrite even more than the vanadium alone, secondly, with chromium in order to facilitate the effectiveness of the controlled cooling at the time of the transformation operation, and thirdly, with silicon, itself alphagenic, to increase resilience, but also to favor the precipitation at the grain joints of a ferrite which will prevent the bainite from invading everything and thus will allow the acicular ferrite to appear in order to take its rightful place.

It should be recalled here that acicular ferrite is a metallographic constituent known in siderurgy. It already is used, for example, as shown in EP-A No. 0288054, to facilitate the process for manufacture of fine-grained sheets for low-temperature use (offshore, etc..) by eliminating the intermediate reheating state between casting and hot-rolling.

Likewise, as shown in USP No. 6,669,789, it is known to make use, aside from the customary polygonal ferrite-perlite, of an acicular ferrite structure (that forms on the carbides) for the manufacture

of titanium steel sheet with high resistance and ample elongation in order to limit the austenitic grain size starting from hot-rolled thin slabs.

The invention will be well understood and other aspects and advantages will emerge more clearly in view of the detailed description that follows, given by way of an embodiment example.

There are produced by continuous casting in the steelworks long semiproducts (billets or blooms) deriving from a steel having, besides, iron, the following composition by weight content in relation to the iron:

From 0.2 to 0.5% carbon. At these contents, the carbon makes it possible to obtain good mechanical resistance characteristics. In particular, the required resilience is ensured by the 0.2% minimums. On the other hand, the content thereof should not be too high (approximately 0.5% maximum), in order not to favor the formation of bainite instead of the sought acicular ferrite.

From 0.5 to 2.0% manganese. Manganese ordinarily is used here in order to increase the temperability of the steel with the aforementioned carbon contents. However, the content thereof preferably is less than 2.0% in order to avoid its segregation which would impair the homogeneity of the structure.

From 0.05 to 0.5% vanadium. Vanadium favors the development of acicular ferrite, as already stated, by making it possible to increase the size of the bainitic areas and by shifting them to the high temperatures. It also reduces the area of occurrence of perlite ferrite.

From 0.02 to 0.10% sulfur. Sulfur not only improves the machinability of the parts, but performs a function mainly sought here in the mechanism of nucleation of the acicular ferrite. It has been discovered, in fact, that it is the sulfurs, and not the carbides as in the case of the document USP 6,669,789 mentioned above, which actually constitute essential anchoring points on which the grains of acicular ferrite, the development of which is going to be promoted by the vanadium, alloyed with silicon, are going to form.

From 0.6 to 1.5% silicon. Silicon usually serves to deoxidize the steel. Its content here, however, should remain below 1.5% in order not to weaken the steel. Here it performs an essential function in the controlled growth of the bainitic area in which the acicular ferrite is formed by precipitating the primary ferrite at the grain joints, as already indicated, and thus allowing the vanadium to promote the development of acicular ferrite.

From 0.05 to 1.0% chromium. The chromium makes it possible to adjust the temperability of the grade and thus to follow the increase in size of the parts to be produced. It also acts with the silicon in order to increase the range of presence of the acicular ferrite.

From 0.01 to 0.5% molybdenum. Molybdenum contributes to the obtaining of the final structure through an adjustment of the temperability of the grade. In fact, if the content of tempering elements is too low, a ferrite-perlitic structure will be obtained, and conversely, an excessively tempering grade may lead to the obtaining of martensite or residual austenite.

Optionally, but highly recommended in practice, from 0.01 to 0.02% titanium in order to protect the elements from nitrogen and in particular to keep free vanadium in sufficient quantity, for otherwise it might form precipitated nitrides too readily.

Likewise optionally, but ordinarily widely used in practice, from 5 to 30 ppm of calcium in order to improve the castability of the steel and its implementation. It facilitates the obtaining of oxide inclusions which may enter into the mechanism of nucleation of the acicular ferrite.

Possibly up to 50 ppm of boron that will act in synergy with the molybdenum to broaden the bainitic area in which the acicular ferrite is formed.

Possibly up to 0.2% aluminum for control of the austenitic grain size, but it also will perform a function in the preservation of vanadium.

This optimized composition makes it possible for the steel to have, following a controlled cooling, a structure essentially composed of acicular ferrite. By essentially there will be understood an acicular ferrite content of more than 50% and preferably more than 60%, and advantageously approximately 80% or even more. Such a metallographic structure makes it possible for the steel to have good mechanical characteristics of resistance, hardness and ductility, but also an enhanced resistance to impacts and to fatigue effect.

As is going to be seen, the acicular ferrite is obtained before or after forming of the part, but in any case by means of a controlled cooling of the steel.

In the first case, deformation is performed cold on a steel already having a structure essentially composed of acicular ferrite. There is provided a long semiproduct composed of a steel with an analysis according to the invention, which is hot-rolled as need be after a reheating above 1100° C, in accordance with customary hot-rolling practice, until obtaining of a rolled wire 10 mm in diameter, for example. The removal temperature of the wire is on the order of 900 to 950° C. The rolled wire obtained is cooled with blown air in the rolling "heat" itself in the customary manner ("Steelmor" process, for example). If its diameter so permits, the wire also may be cooled naturally to the ambient atmosphere.

The rolled wire is delivered in ring form to the transformer which is going to cut it into pieces of required length and subject them to a cold press for obtaining of the desired parts. The final mechanical characteristics are obtained naturally by the cold-drawing resulting from forming.

In the second case, plastic deformation is performed "hot" and the metallographic structure is obtained directly on the rough forge shapes. There is provided a long semiproduct composed of a steel with an analysis according to the invention, which is hot-rolled until giving it a diameter of 35 mm, for example. After possible cooling, which does not need to be controlled at this level, the bar is positioned lengthwise and delivered to the smith customer.

The bars then are cut into pieces. Each piece is brought to a temperature of at least 1100° C by means of an induction furnace. This heating also can be performed more classically, but the heating conditions (heating time, speed, etc...) then must be optimized in order to obtain a homogeneous austenitic structure having a grain size favorable to the formation of acicular ferrite. The austenitic grain size then is estimated at 80 μm . The pieces are subjected to a hot plastic deformation operation. Forging is concluded at a temperature in excess of 1100° C. The rough shapes of parts obtained in this manner then undergo a forced cooling to room temperature at a cooling speed ranging from approximately 0.5 to 15° C/s, depending on the diameter of the part and the optimization of the steel

composition. The part also may be cooled in a natural but controlled manner by placing the rough shapes at the forge outlet one by one on a conveyor belt, for example. The part then is machined to conform to the final intended dimensions. Instead of machining, the part possibly may be subjected to a second plastic deformation. This additional operation may be carried out cold without running the risk of cracking the part because of the ductile nature imparted to the steel by the microstructure. It is not necessary to implement a thermal hardening and tempering in order to obtain the intended mechanical characteristics.

The grade of steel according to the invention makes it possible to obtain a part with metallographic structure essentially composed of acicular ferrite. It has the mechanical characteristics of resistance to breaking and hardness required for its usage properties, and meets the requirements for machinability. In addition, it has an increased tenacity by virtue of its very structure, in which the entanglement of the laths serves as a barrier to the occurrence and the propagation of cracks. This increased tenacity in fact enables it, as a result, also to have a better resistance to impacts and a better resistance to fatigue. Furthermore, it also makes possible a second cold forming by press, for example. The obtaining of acicular ferrite also make it possible to increase the mechanical resistance of the grade through the ample dispersal density of its laths.

Tests were conducted in the laboratories of the producer of semiproductions for a forge deriving from continuous casting. A wheel hub was forged there from a steel according to the invention, the chemical composition of which, besides iron and the impurities resulting from processing, correspond to the following analysis:

% C	% Mn	% V	% Si	% Cr	% Mo	ppm B	% S	ppm Ca	% Ti	% Al
0.31	1.33	0.12	1.18	0.28	0.03	20	0.04	11	0.015	0.02

Prior to forging, this piece was heated to 1200° C by induction. The end temperature of forging is 1100° C. After forging, the rough shape is cooled at a speed of 2° C/s directly in the heat. No other thermal treatment is applied.

The structure obtained on this test hub is 80% acicular ferrite; it also has the following mechanical characteristics:

R _m (MPa)	R _{p0.2} (MPa)	Hardness (HV)	A (%)	Z (%)
1150	800	300	11	25

It is recalled that:

- R_m represents the resistance to breaking corresponding to the maximal force before breaking with reference to the initial section of the wire.
- R_{p0.2} represents the conventional limit of elasticity corresponding to the force with reference to the initial section of the wire producing a plastic elongation of 0.2%.

- A represents the breaking elongation.
- Z represents the area contraction corresponding to the reduction of the wire section after breaking.

It goes without saying that the invention could not be limited to the example that has just been described, a wheel hub, but that it extends to numerous variations or equivalents, in type of parts and in size and dimension, insofar as the definition thereof given in the attached claims is observed.